Automated Euler and Navier-Stokes Database Generation for a Glide-Back Booster

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Abstract
AeroDB is a new software tool that is used to compute thousands of Euler and Navier-Stokes solutions for a 2nd generation glide-back booster in one week. Process automation and web-based access is used to greatly simplify and reduce the user workload. The solutions are validated with experimental data, and stability derivatives are computed using a monotone cubic spline procedure. Flow visualization and three-dimensional surface plots are used to interpret and characterize the nature of computed flow fields.

1 Introduction

The past two decades have seen a sustained increase in the use of high fidelity Computational Fluid Dynamics (CFD) in basic research, aircraft design, and the the solution of post-design issues. As the fidelity of a CFD method increases, the number of cases that can be readily and affordably computed greatly diminishes. However, computer speeds now exceed 2 GHz, hundreds of processors are currently available and more affordable, and advances in parallel CFD algorithms scale more readily with large numbers of processors. All of these factors make it feasible to compute thousands of high fidelity cases. However, there still remains the overwhelming task of monitoring the solution process.

Automation can reduce the tedious and error prone nature of the process which can easily overwhelm a team of engineers. ILab [1] is an example of a general purpose parameter study tool, but it's generality requires a significant amount of user input. Chaderjian et. al. [2] is another example of process automation in which PERL scripts were used to generate a database of time-dependent Reynolds-averaged Navier-stokes (RANS) solutions. These scripts greatly reduced the user workload, but used only one CFD code and one geographical site.

The objective of this paper is to present a software tool that improves on the previous examples, and demonstrates its capabilities by computing at least 100 RANS solutions and 1000 Euler solutions in one week for a 2nd generation Liquid Glide-Back Booster (LGBB) design. The solution method is described in Section 2, results of the database generation are discussed in Section 3, and concluding remarks are made in Section 4.

2 Solution Procedure

Grid computing [3] is based on the concept that one can gain significant increases in computational throughput by accessing any number of computers at remote sites. One example is NASA's Information Power Grid (IPG), which consists of distributed heterogeneous computer systems at different NASA and supercomputer centers in the United States. AeroDB is a software system presented in this paper that utilizes NASA's IPG and the Globus toolkit [4], which provides common secure services for user authentication over an open network.

A flowchart of AeroDB is shown in Fig.1 and consists of a system of PERL modules, MySQL database, and web portal. The web portal is used to submit a run matrix to AeroDB anywhere there is internet access. It is also used to select the flow solver, number of CPUs per case, etc. A Job Launcher (JL) script is continually running in the background on a front-end machine and checks the database for cases to run. The JL uses the Globus toolkit for remote site authentication, and also utilizes a Resource Discovery Broker to decide where to submit the jobs. The present application uses 13 computers at 4 different geographical sites across the United States.

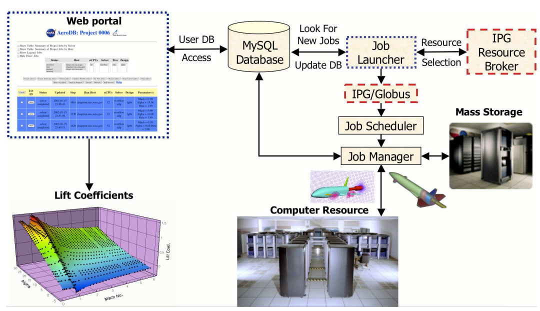


Fig. 1. AeroDB flowchart.

The JL submits the job to the Job Scheduler (JS), which starts the Job Manager (JM) at the remote site. The JM gets job attributes from the MySQL database. Once a job begins to run, a Run Manager (RM) in the CFD code monitors flow solver convergence and the time remaining in the execution queue. If the RM determines that the solution is converged or the queue time is depleted, it sends a signal to the JM to stop the run, and if needed, resubmit the job for continued execution. The JM also transfers updated solution files to the mass storage system and MySQL database. AeroDB can be run on non-grid enabled systems using ssh for authentication. In such cases, the Resource Discovery Broker is not available.

The current application solves the steady Euler equations with the Cart3D Euler code [6] using unstructured Cartesian grids. The steady RANS equations are solved with the Overflow code,[7] which uses overset structured grids to model complex geometries. Other CFD codes are also available in AeroDB. The RM is installed in each CFD code.

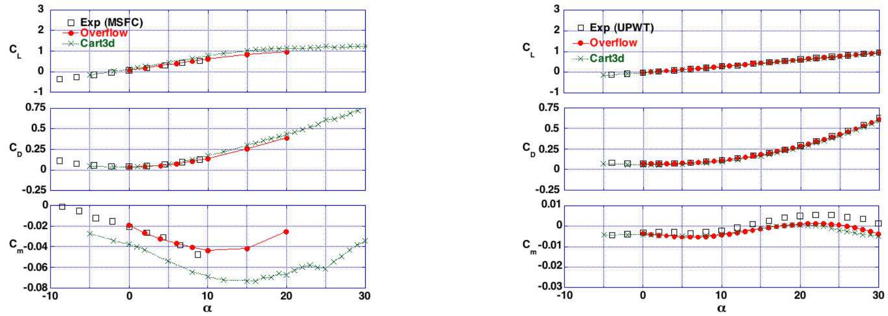
3 Numerical Results

AeroDB is used to generate a database of Euler and Navier-Stokes solutions for the LGBB geometry, (see Fig. 3). Inviscid (Cart3D) computations were carried out using 38 Mach numbers ($0.2 \leq M_\infty \leq 6.0$), five sideslip angles ($0 \leq \beta \leq 4$ deg), and angles of attack -5 $\leq \alpha \leq$ 30 deg. Navier-Stokes (Overflow) computations were also carried out using 14 Mach numbers ($0.2 \leq M_\infty \leq 3.0$), and five sideslip angles ($0 \leq \beta \leq 4$ deg). The angles of attack for viscous cases were $0 \leq \alpha \leq 20$ deg for subsonic flows, and $0 \leq \alpha \leq 30$ deg for supersonic flows. The goal of computing at least 100 Overflow cases and 1000 Cart3D cases in one week was fully met within a 72 hour time period using AeroDB. At the end of seven days, 211 Overflow cases and 2863 Cart3D cases were completed. The current LGBB CFD database consists of 3666 cases, (499 Overflow solutions and 3167 Cart3D solutions).

The CFD database is validated through a grid refinement study and comparison of the computed results with wind tunnel data. The Overflow RANS solutions are computed at flight Reynolds number (Re) conditions using the Spalart-Allmaras turbulence model.[8] The Reynolds number is chosen according to a flight trajectory scenario. The Overflow grid consists of 8.5 million grid points, and the Cart3D grid consists of 1.4 million cells, which provides good grid support for the present parameter study, see Ref. [9].

Figure 2 compares the computed lift coefficient (C_L), drag coefficient (C_D), and pitching moment coefficient (C_m) with transonic and supersonic wind-tunnel data. The Overflow lift, drag and pitching moment coefficients compare very well with the experiment. The Cart3D lift and drag coefficients compare equally well with the experiment, but under predict the transonic pitching moment coefficient somewhat. Transonic shock positions can be sensitive to viscous effects.

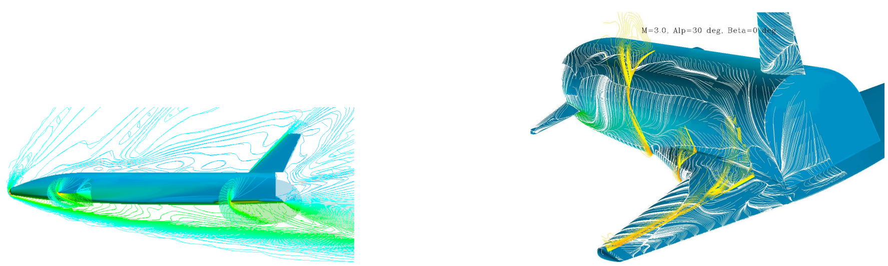
Visualization of a viscous supersonic case is shown in Fig. 3. Figure 3(a) shows Overflow pressure coefficient contours at the symmetry plane, on the LGBB surface, and two cutting planes through the canard and wing. Shocks occur near the vehicle nose, leading and trailing edges of the canard and wing,



(a) $M_\infty = 0.9, Re = 60 \times 10^6$. (b) $M_\infty = 3.0, Re = 32 \times 10^6$.

Fig. 2. Comparison of computed C_L, C_D, and C_m with wind-tunnel data.

and along the vertical tail. The Cp contours at the tail end of the fuselage also indicate separated flow. Figure 3(b) shows the viscous surface flow topology (white), and off-surface vortical flows highlighted by helicity-density contours (yellow). It is remarkable how complex the surface-flow topology is. However, due to domain-of-influence (DOI) effects, these separated regions are steady and confined very close to the body. This helps explain why there are very little viscous effects shown in the supersonic Euler and Navier-Stokes C_L and C_D, but more significant effects for C_m (see Fig.2).

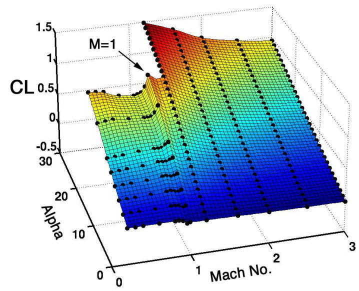


(a) C_p contours, (blue $\rightarrow$ low, green $\rightarrow$ high). (b) Surface flow (white), helicity-density (yellow).

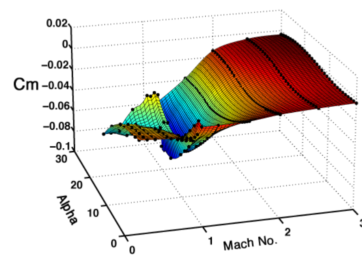
Fig. 3. Viscous flow visualization. $M_\infty = 3.0, \alpha = 30°, Re = 32 \times 10^6$.

Figure 4 shows the variation of Overflow C_L and C_m with Mach number and angle of attack. Symbols indicate computed cases and lines represent values obtained by using a monotone cubic-spline interpolation procedure.[9]

The lift coefficient shows a trend of increasing lift with angle of attack, and a compressibility rise/fall near $M = 1$, as expected. The pitching moment coefficient shows a relatively flat behavior in the supersonic region due to shock positions being fixed near wing/canard trailing edges, and a dramatic valley in the transonic region. Here, the shock position plays an important role in determining the shape of this valley.



(a) Overflow C_L.



(b) Overflow C_m.

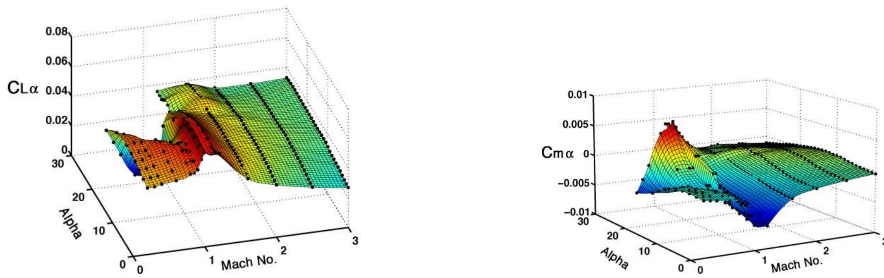
Fig. 4. Viscous force/moment database.

Figure 5 shows the variation of the longitudinal stability derivatives, C_{L_α} and C_{m_α} with Mach number and angle of attack. These surfaces were generated by numerically differentiating the data with the monotone procedure. Using the monotone procedure helps control spurious oscillations and provides reasonable slope information.

Inviscid (Cart3D) results show similar trends as the viscous (Overflow) cases, see Chaderjian et al.[9]

4 Conclusions

The ability to automate and manage the solution process for generating thousands of Euler and Navier-Stokes CFD solutions has been demonstrated using AeroDB. The primary goal of computing at least 100 Navier-Stokes solutions and 1000 Euler solutions for a LGBB geometry in one week was fully met in 72 hours using 13 computers at 4 different geographical sites across the United States (the NASA IPG). After seven days, 211 viscous cases and 2863 inviscid cases were completed, and the current database consists of 3666 cases, (499 viscous and 3167 inviscid). The results compared well with experimental data and showed expected trends. Longitudinal stability derivatives were also computed by numerically differentiating the forces and moments using a monotone cubic-spline procedure.



(a) Overflow C_{L_α}. (b) Overflow C_{m_α}.

Fig. 5. Viscous longitudinal stability derivatives.

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